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Q9 23. (Amended) A chrome plated part according to claim ~~5~~⁴, wherein the upper chrome layer has tensile residual stress.

26. (Amended) A chrome plated part according to claim ~~23~~⁵, wherein the upper chrome layer has a crystal grain and the crystal grain has a size less than 9 nm.

Q10 12
27. (Amended) A chrome plated part comprising:
a substrate having a surface; and
a chrome layer deposited on the surface of the substrate by electroplating,
the chrome layer having compressive residual stress of 100 MPa or more.

Q11 24
29. (Amended) A chrome plating method comprising the steps of:
providing a substrate having a surface; and
depositing a chrome layer on the surface of the substrate by electroplating so that the chrome layer has compressive residual stress of 100 MPa or more.

REMARKS

Further and favorable reconsideration is respectfully requested in view of the foregoing amendments and following remarks.

Initially, the specification has been amended to clarify the invention and also to correct a typographical error.

Claims 24, 25, 28 and 30 have been canceled; and claims 1-3, 5, 6, 8, 9, 23, 26, 27 and 29 have been amended.

Amended claim 1 incorporates the compressive residual stress value from claim 2, and claim 2 has been amended to recite the compressive residual stress of 150 MPa or more, for example as disclosed at page 26, lines 17-18 of the specification. The same type of amendments have been made in claims 8 and 9.

Attached hereto is a marked-up version of the changes made to the Specification and claims by the current amendment. The attached page is captioned "Version with markings to show changes made."

In response to the objection to claims 21 and 22 in item 1 on page 2 of the Office Action, claim 3 has been amended to depend only from claim 2, as a result of which this objection has been rendered moot.

Claims 28 and 30 have been canceled, thus rendering moot the objection to these claims in item 2 of the Office Action.

In response to the objection to claims 23 and 25 in item 3, claim 25 has been canceled, and claim 23 has been amended to refer to tensile residual stress instead of compressive residual stress, thus rendering the objection moot.

In response to the rejection of claims 1-7 and 21-30 under the first paragraph of 35 U.S.C. § 112, the claims have been amended to refer to electroplating instead of plating, thus rendering the rejection moot.

The patentability of the present invention over the disclosures of the references relied upon by the Examiner in rejecting the claims will be apparent upon consideration of the following remarks.

Thus, all of the prior art rejections set forth in items 7-18 are respectfully traversed.

The basis for these rejections appears to be the Examiner's opinion that compressive residual stress is an inherent characteristic of a crack-free chromium layer. That is, the Examiner takes the position that the present claims are anticipated or rendered obvious on the basis of the disclosures of references describing a crack-free chrome layer, although the references make no mention or suggestion that residual stress of a crack-free chrome layer is compressive.

In actuality, however, crack-free chrome layers generally exhibit tensile residual stress. For example, please refer to the attached article ("Effect of Pulsed Current on the Properties of Electrodeposited Chromium" appearing in the magazine "PLATING AND SURFACE FINISHING", November, 1989), where it is described in the paragraph under "Results" on page 65 that deposits produced at 2500 Hz were crack-free, and further it is indicated in Fig. 2 on the same page that these deposits exhibit a tensile residual stress as high as 0.4 kN/mm (=400 MPa) or more.

As is apparent from the above, conventional chrome layers formed by plating generally exhibit tensile residual stress even when they are crack-free. Therefore, the Examiner's opinion is not correct.

Table II in U.S. Patent No. 3,318,786 submitted with Applicants' IDS indicates a crack-free chrome layer exhibiting compressive residual stress, and this stress is of an extremely low value [-32

P.S.I. $\times 10^{-3}$ ($=0.00023$ MPa)]. In view of this, claims 1, 8, 27 and 29 have been amended whereby "having compressive residual stress" now reads "having a compressive residual stress of 100 MPa or more". Further, claims 2 and 9 have been amended to change "having a compressive residual stress of 100 MPa or more" to "having a compressive residual stress of 150 MPa or more".

In conventional crack-free chrome layers, residual stress appears as tensile stress or extremely low compressive stress close to zero. With a lapse of time or under the effect of heat, such tensile residual stress tends to increase and extremely low compressive stress changes to tensile stress, resulting in the formation of cracks. In the present invention, the residual stress of the chrome layer comprises high compressive stress, and thus regardless of any lapse of time or application of heat there is no change in the compressive nature of the stress. Even in the case that residual stress shifts to the tensile side, it does not reach a level where cracks are formed.

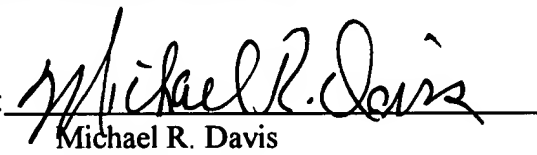
Accordingly, since the primary basis for the prior art rejections, i.e. that compressive residual stress is an inherent characteristic of a crack-free chromium layer, is erroneous, it is Applicants' position that all of these rejections should be withdrawn.

Therefore, in view of the foregoing amendments and remarks, it is submitted that each of the grounds of rejection has been overcome, and that the application is in condition for allowance. Such allowance is solicited.

Respectfully submitted,

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The centerless polishing disk apparatus 20 comprises a buff wheel 20a and a regulating wheel 20b. After completion of the chrome plating process, the work W is polished between the buff wheel 20a and the regulating wheel 20b of the centerless polishing disk apparatus 20 and rolls on the inclined stand-by member 24 to the secondary line L_2 , where the work W is continuously moved through the high-frequency coil 22 and the cooling coil 23 by extension of a rod 21a of the pusher 21. Thus, polishing and heat oxidation can be efficiently conducted.

Example 1

Using rods (diameter: 12.5 mm; length: 200 mm) made of steel (JIS S25C) as test pieces and a chrome plating bath comprising 250 g/L of chromic acid, 2.5 g/L of sulfuric acid, 8 g/L of organic sulfonic acid and 10 g/L of boric acid, pulse plating was conducted under the following conditions: bath temperature = 60°C; maximum current density $I_u = 120$ A/dm²; minimum current density $I_L = 0$ A/dm² (the same as in the case of Fig. 2); pulse time (on-time) T_1 at maximum current density $I_u = 100$ to 800 μ s; pulse time (off-time) T_2 at minimum current density $I_L = 100$ to 500 μ s; and frequency = 0.8 to 5.0 kHz. As a result, a lower chrome layer S_1 (Fig. 1) having a thickness of about 3 μ m was formed on a surface of each test piece. Subsequently, in the same chrome plating bath, general-purpose plating was conducted at a bath temperature of 60°C and a current density of 60 A/dm². As a result, an upper chrome layer S_2 (Fig. 1) having a thickness of about 10 μ m was formed on the lower chrome

layer S_1 on each test piece, to thereby obtain samples 2 to 18 (as shown in Table 2). Further, for reference, using the same test piece and chrome plating bath as mentioned above, general-purpose hard chrome plating was conducted at a bath temperature of 60°C and a current density of 60 A/dm². As a result, a single chrome layer having a thickness of about 20 μ m was formed on a surface of the test piece, to thereby obtain a sample 1.

With respect to the samples 2 to 18, a surface hardness (HV) was measured and visual observation was made by using a microscope to evaluate formation of cracks in each of the lower and upper chrome layers S_1 and S_2 ^{after deposition}. Further, with respect to the lower chrome layer S_1 , residual stress and crystal grain size were measured as mentioned below.

Further, the samples 2 to 18 were subjected to a salt-spray test in accordance with JIS Z2371, and visually observed to evaluate occurrence of rusting. With respect to the samples in which no rusting was observed, they were subjected to heat treatment at 200°C for 2 hours. The resultant samples were visually observed to evaluate formation of cracks on each of the lower and upper chrome layers S_1 and S_2 in the above-mentioned manner, and were subjected to the salt-spray test in accordance with JIS Z2371 again to evaluate occurrence of rusting. The color of a surface of each of the samples 2 to 18 was observed at the time of completion of formation of the lower chrome layer S_1 . The above-mentioned measurements and observations were also conducted with respect to the single chrome layer of the sample 1.

✓ after deposition

Sample No.	Pulse time (μs)		Crystal grain size of S ₁ (nm)	Cracking of S ₁	Residual stress (MPa)	Hardness (HV)	Appearance of S ₁	Rusting		Evaluation
	T ₁	T ₂						Before heat treatment	After heat treatment	
1 (Comparative)			6.1	Observed	+230	1,090	Glossy	Observed (2h)		NG
2 (Comparative)	100	100	7.8	Observed	+276	1,034	Glossy	Observed (24h)		NG
3 (Comparative)	200	100	8.0	Observed	+160	1,017	Glossy	Observed (24h)		NG
4 (Comparative)	150	150	8.2	Observed	+10	940	Glossy	Observed (96h)		NG
5 (Comparative)	200	200	8.7	Not observed	-65	920	Glossy	Not observed (300h)	Observed (24h)	NG
6 (Present invention)	150	200	9.6	Not observed	-150	870	Glossy	Not observed (300h)	Not observed (300h)	OK
7 (Present invention)	100	200	9.8	Not observed	-203	835	Glossy	Not observed (300h)	Not observed (300h)	OK
8 (Present invention)	110	220	10.1	Not observed	-220	840	Glossy	Not observed (300h)	Not observed (300h)	OK
9 (Present invention)	800	300	10.5	Not observed	-205	818	Glossy	Not observed (300h)	Not observed (300h)	OK

Table 2 (1)

after deposition

Sample No.	Pulse time (μs)		Crystal grain size of S ₁ (nm)	Cracking of S ₁	Residual stress (MPa)	Hardness (HV)	Appearance of S ₁	Rusting		Evaluation
	T ₁	T ₂						Before heat treatment	After heat treatment	
10 (Present invention)	400	300	10.6	Not observed	-305	782	Glossy	Not observed (300h)	Not observed (300h)	OK
11 (Present invention)	200	300	11.1	Not observed	-339	742	Glossy	Not observed (300h)	Not observed (300h)	OK
12 (Present invention)	300	300	11.7	Not observed	-313	710	Glossy	Not observed (300h)	Not observed (300h)	OK
13 (Present invention)	600	400	12.3	Not observed	-323	681	Glossy	Not observed (300h)	Not observed (300h)	OK
14 (Present invention)	500	400	13.5	Not observed	-334	630	Glossy	Not observed (300h)	Not observed (300h)	OK
15 (Present invention)	400	400	15.4	Not observed	-272	602	Glossy	Not observed (300h)	Not observed (300h)	OK
16 (Comparative)	300	400	16.0	Observed	+30	546	Milky	Observed (96h)		NG
17 (Comparative)	600	500	16.7	Observed	+53	498	Milky	Observed (96h)		NG
18 (Comparative)	700	500	18.1	Observed	+18	450	Milky	Observed (96h)		NG

Table 2 (2)

of about 5 μm was formed on the intermediate chrome layer S_4 , to thereby obtain a sample.

With respect to the obtained sample, each of the lower chrome layer S_1 , the intermediate chrome layers S_3 and S_4 and the upper chrome layer S_2 was visually observed by using a microscope to evaluate formation of cracks. Further, by the same methods as mentioned above in Example 1, residual stress and crystal grain size were measured with respect to each of the chrome layers S_1 to S_4 . The sample was subjected to the salt-spray test in accordance with JIS Z2371, and visually observed to evaluate occurrence of rusting. After the salt-spray test, the sample was subjected to heat treatment at 200°C for 2 hours, and subjected to the salt-spray test in accordance with JIS Z2371 again. The resultant sample was visually observed to evaluate occurrence of rusting. Results of the above-mentioned measurements and observations are shown in Table 3.

Table 3

Chrome layer	Residual stress (MPa)	Crystal grain size (nm)	Cracking	Rusting	
				Before heat treatment	After heat treatment
S_1	-279	12.2	Not observed	Not observed	Not observed
S_3	-163	10.7	Not observed		
S_4	+226	8.0	Slightly observed		
S_2	+300	6.6	Observed		

Subsequently, in the same chrome plating bath, general-purpose plating was conducted at a bath temperature of 60°C and a current density of 60 A/dm². As a result, a cracked upper chrome layer S₂ (Fig. 1) having a thickness of about 10 μm was formed on the lower chrome layer S₁ on each test piece. The upper chrome layer S₂ was finished by buffing so as to have a surface roughness Ra of 0.08 μm. As a result, samples 31 and 32 were obtained. The sample 31 was subjected to a general-purpose baking process at 210°C for 4 hours, to thereby form an oxide film (containing Cr₂O₃ as a main component) on the upper chrome layer S₂. The sample 32 was subjected to high-frequency heating at a maximum heating temperature of 400°C for a short period of time (about 10 seconds), to thereby form an oxide film (containing Cr₂O₃ as a main component) on the upper chrome layer S₂.

For comparison, using the same test piece and chrome plating bath as used in Example 1, pulse plating was conducted under the following conditions: bath temperature = 60°C; maximum current density I_v = 120 A/dm²; minimum current density I_L = 0 A/dm²; on-time T₁ = 200 μs; off-time T₂ = 200 μs; and frequency = 2.5 kHz. As a result, a ~~cracked~~ ^{crack-free} lower chrome layer S₁ having a thickness of about 3 μm was formed on a surface of the test piece. Subsequently, in the same chrome plating bath, general-purpose plating was conducted at a bath temperature of 60°C and a current density of 60 A/dm². As a result, a cracked upper chrome layer S₂ having a thickness of about 10 μm was formed on a surface of the lower chrome layer S₁, to thereby obtain a sample 33. The

sample 33 was subjected to the above-mentioned buffing and high-frequency heating. Further, for comparison, substantially the same procedure for obtaining the sample 31 was repeated, except that the baking process was conducted
5 before buffing, to thereby obtain a sample 34.

With respect to each of the samples 31 to 34, residual stress and crystal grain size of the lower chrome layer S_1 were measured by the same methods as mentioned above in Example 1. The samples 31 to 34 were subjected to the salt-
10 spray test in accordance with JIS Z2371, and visually observed to evaluate formation of red rust and white rust. Results of the above-mentioned measurements and observations are shown in Table 4.

Table 4

Sample No.	Process	Crystal grain size of S_1 (nm)	Residual stress of S_1 (MPa)	Method of heat oxidation	Rusting	
					White rust	Red rust
31	Plating-Polishing-Oxidation	11.7	-313	Baking	Not observed	Not observed
32	Plating-Polishing-Oxidation	11.7	-313	High-frequency heating	Not observed	Not observed
33	Plating-Polishing-Oxidation	8.7	-65	High-frequency heating	Not observed	Observed
34	Plating-Oxidation-Polishing	8.7	-65	Baking	Observed	Not observed

1. A chrome plated part comprising a substrate having a crack-free chrome layer on a surface thereof, the crack-free chrome layer having compressive residual stress of 100 MPa or more and being formed by [plating] electroplating.
2. A chrome plated part [according to claim 1, wherein the compressive residual stress in the crack-free chrome layer is 100 MPa or more] comprising a substrate having a crack-free chrome layer on a surface thereof, the crack-free chrome layer having compressive residual stress of 150 MPa or more and being formed by electroplating.
3. A chrome plated part according to claim [1 or] 2, wherein the crack-free chrome layer has a crystal grain size of 9 nm or more.
5. A chrome plated part according to claim 1, wherein the crack-free chrome layer is a lower chrome layer and the chrome plated part further comprises a cracked upper chrome layer which is formed on the lower chrome layer by [plating] electroplating.
6. A chrome plated part according to claim 5, further comprising at least one intermediate chrome layer which is formed between the lower chrome layer and the upper chrome layer by [plating] electroplating.
8. A chrome plating method comprising the step of conducting electroplating of a work in a chrome plating bath by application of a pulse current, the chrome plating bath containing organic sulfonic acid, to thereby deposit a crack-free chrome layer on a surface of the work, the crack-free chrome layer having compressive residual stress of 100 MPa or more.
9. A chrome plating method [according to claim 8, wherein the compressive residual stress in the crack-free chrome layer is set to a level of 100 MPa or more by adjusting a waveform of the pulse current] comprising the step of conducting electroplating of a work in a chrome plating bath by application of a pulse current, the chrome plating bath containing organic sulfonic acid, to thereby

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deposit a crack-free chrome layer on a surface of the work, the crack-free chrome layer having compressive residual stress of 150 MPa or more.

23. A chrome plated part according to claim 5, wherein the upper chrome layer has [compressive] tensile residual stress.

26. A chrome plated part according to [any one of] claim 23 [to 25], wherein the upper chrome layer has a crystal grain and the crystal grain has a size less than 9 nm.

27. A chrome plated part comprising:
a substrate having a surface; and
a chrome layer deposited on the surface of the substrate by electroplating,
the chrome layer having compressive residual stress of 100 MPa or more.

29. A chrome plating method comprising the steps of:
providing a substrate having a surface; and
depositing a chrome layer on the surface of the substrate by electroplating so that the chrome layer has compressive residual stress of 100 MPa or more.

